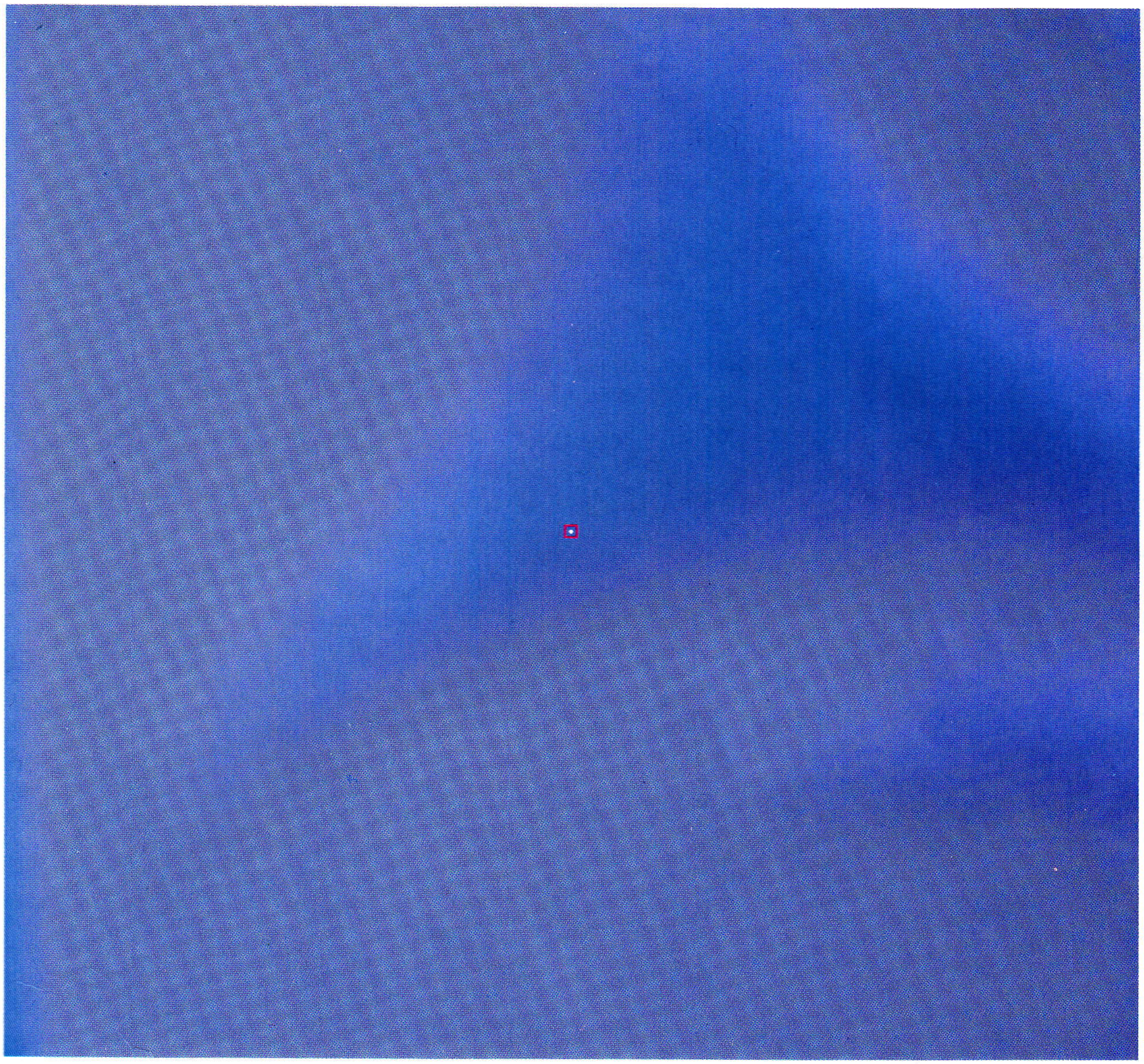
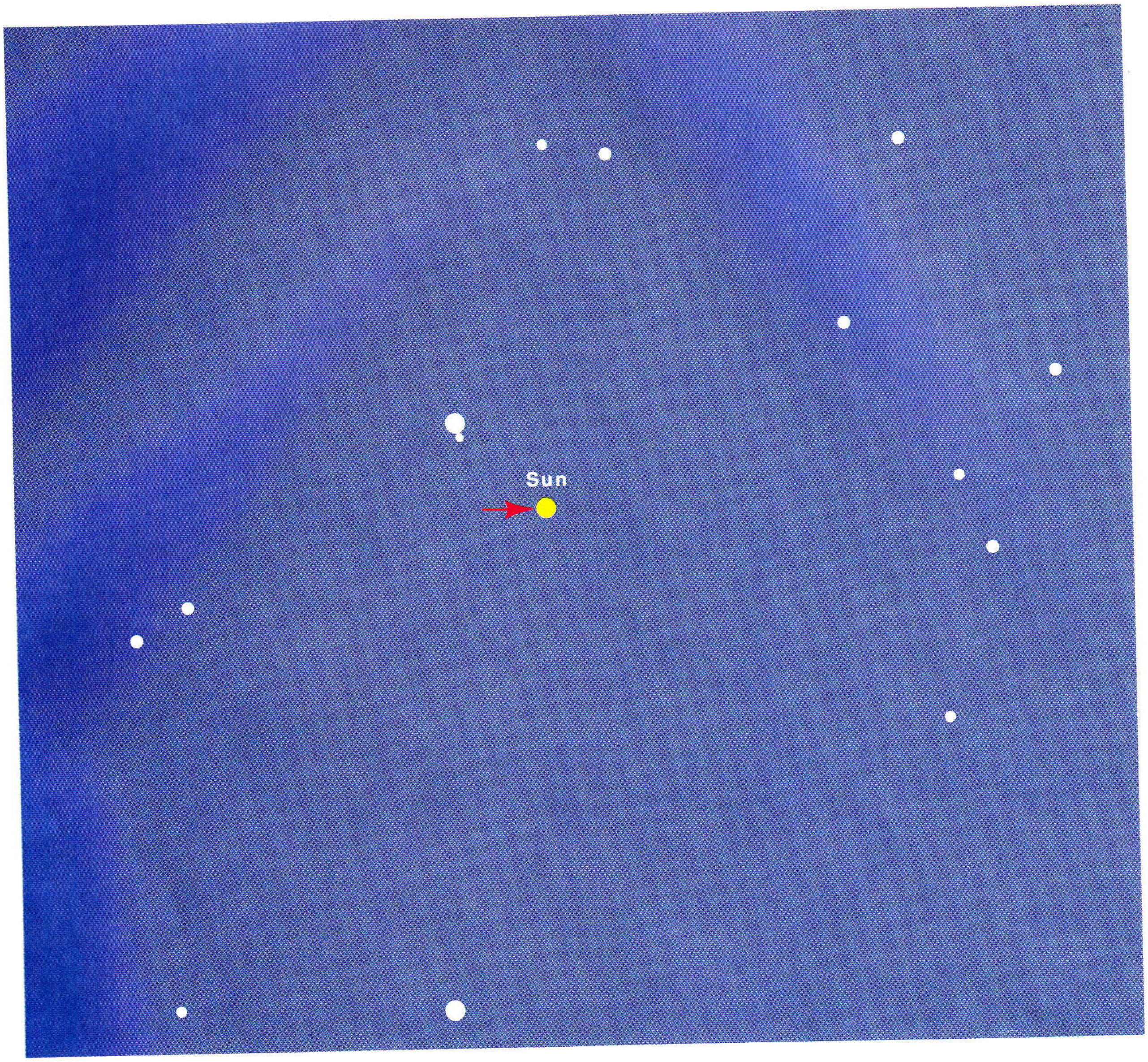


Field of view enlarged 100 times from previous image

When we again enlarge our field of view by a factor of 100, our solar system vanishes. The sun is visible as a point of light, but all the planets and their orbits are now crowded into the small square at the center. None of the sun's family of planets are visible. They are too small and reflect too little light to be visible so near the brilliance of the sun.

Nor are any stars visible except for the sun. The sun is a fairly average star, and it seems to be located in a fairly average neighborhood in the universe. Although there are many billions of stars like the sun, none are close enough to be visible in this diagram of only 11,000 AU in diameter. The stars are typically separated by distances about ten times larger than this diagram. We will see stars in our next field of view, but, except for the sun at the center, this diagram is empty.

It is difficult to imagine the isolation of the stars. If the sun were represented by a golf ball in New York City, then the nearest star would be another golf ball in Chicago. Except for the widely scattered stars and a few atoms of gas drifting between the stars, the universe is nearly empty.

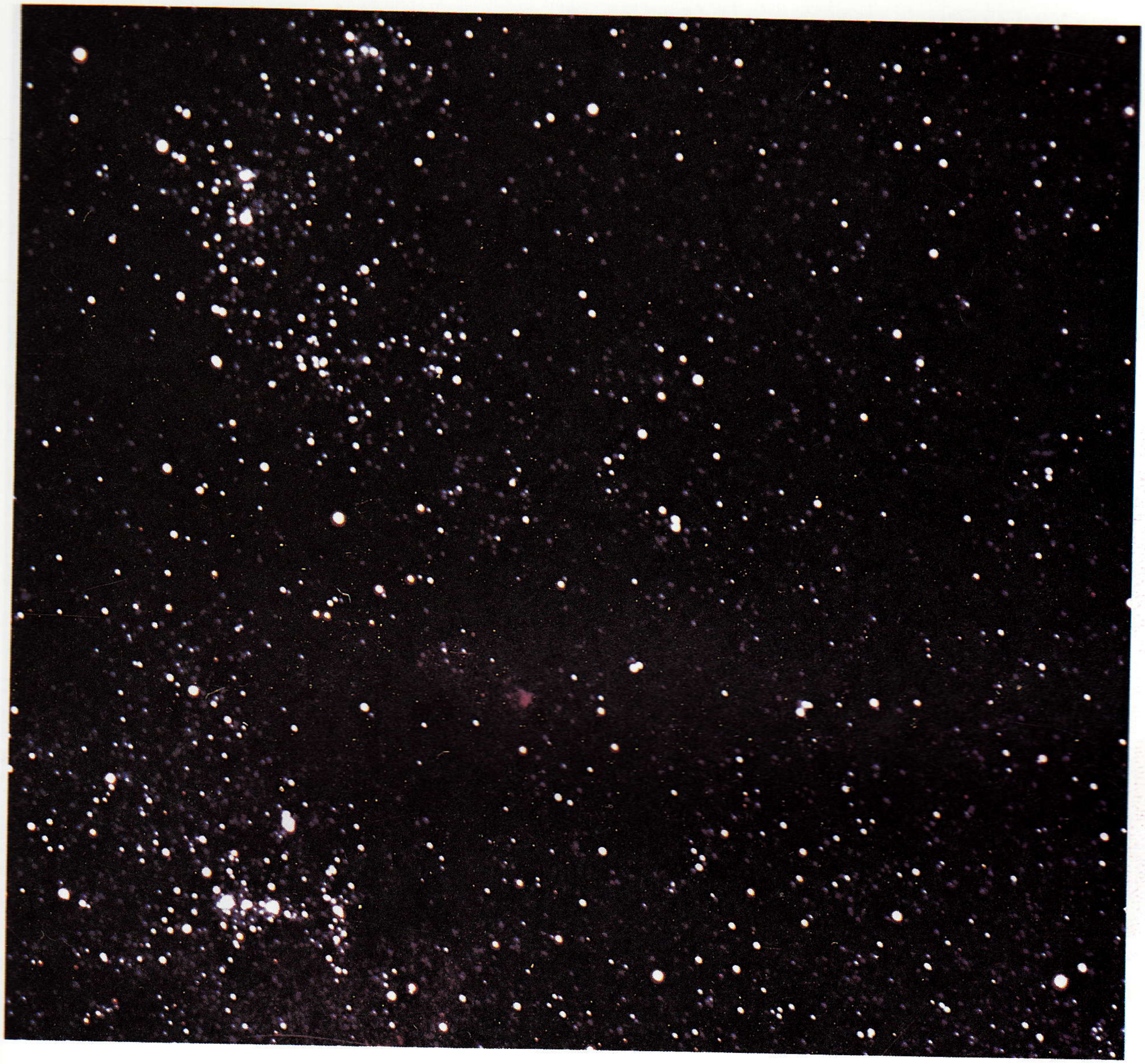


Field of view enlarged 100 times from previous image

Our field of view has now expanded out to a diameter of a bit over 1 million AU. The sun is located at the center, and we see a few of the nearest stars.

These stars are so distant it is not reasonable to quote their distances in astronomical units. We must define a new unit of distance, the light-year. One **light-year** (ly) is the distance that light travels in 1 year, roughly 10^{13} km or 63,000 AU. The nearest star to the sun is Proxima Centauri at a distance of 4.2 ly. Light from Proxima Centauri takes 4.2 years to reach earth. The diameter of our field of view is now 17 ly.

Although these stars have diameters similar to the sun's, they are so far away we cannot see them as anything but points of light. Even looking through the largest telescopes on earth, we still see only points of light. In this diagram, the diameters of the dots represent the brightness of the stars and not their actual diameters. This is the custom in astronomical diagrams, and it is also how star images are recorded on photographs. Bright stars make larger spots on the photographic plate than faint stars, although they may not be larger stars.



Field of view enlarged 100 times from previous image. This box ■ represents relative size of previous frame. (National Optical Astronomy Observatory)

As we expand our field of view by another factor of 100, we find that the sun and its neighboring stars vanish into the background of thousands of stars. The field of view is now 1700 ly in diameter.

Of course, no one has ever journeyed thousands of light years from the sun to photograph the solar neighborhood, so we use a representative photo of the sky. Here the diameters of stars' images are related to the brightness of the stars and not their diameters. The sun is a relatively faint star, so we could no longer locate it on such a photo.

We notice a tendency for stars to occur in clusters. A loose cluster of stars lies in the lower left quarter of the photograph. We will discover that many stars are born in clusters and that both old and young clusters exist in the sky. Star clusters are forming right now.

What we do *not* see is critically important. We do not see the thin gas that fills the spaces between the stars. Although those clouds of gas are thinner than the best vacuum on earth, it is those clouds that give birth to new stars. Our sun formed from such a cloud about 5 billion years ago. We will see more star formation when we expand our field of view by another factor of 100.

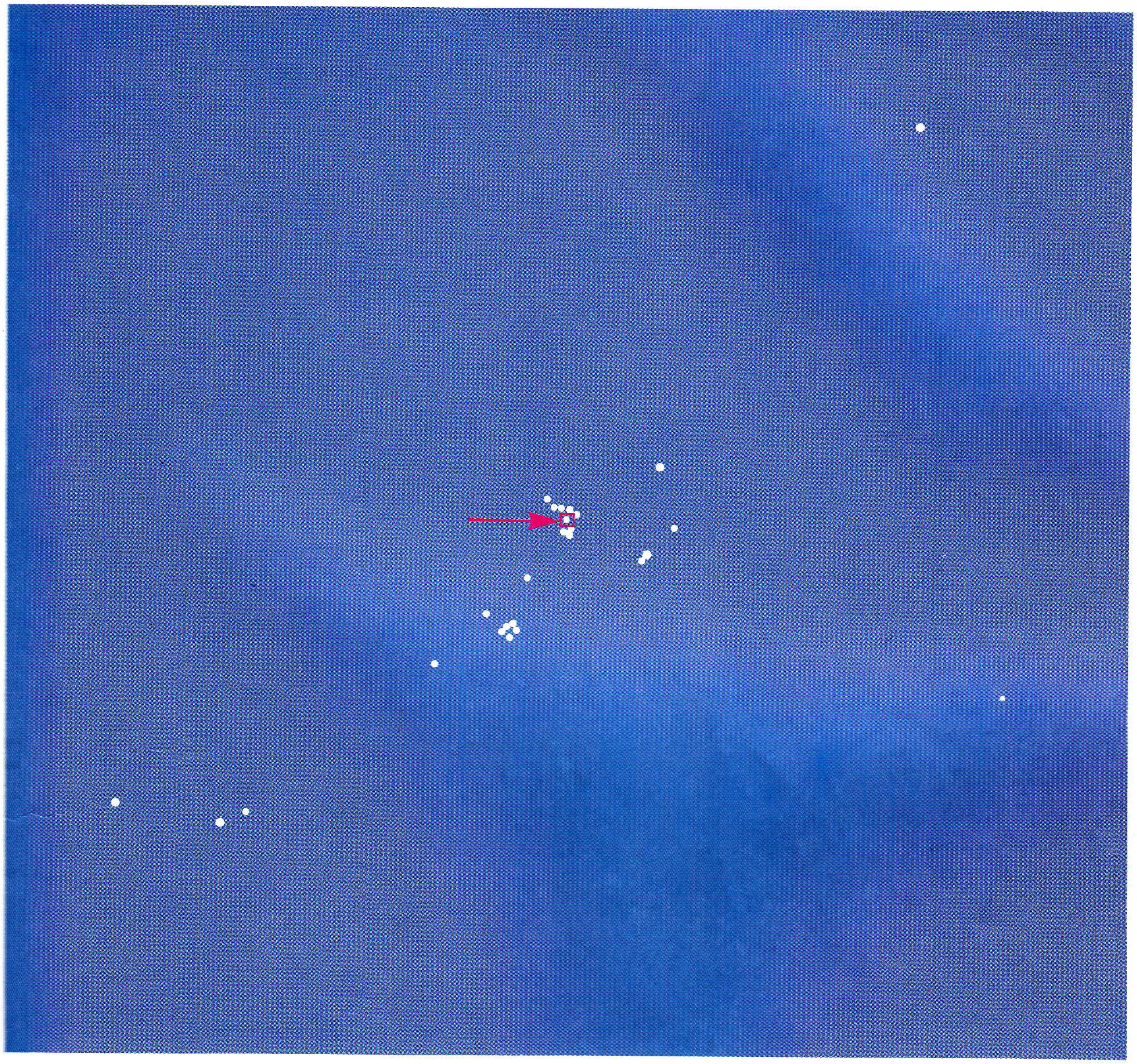
Field of view enlarged 100 times from previous image (©Anglo-American Telescope Board)

If we expand our field of view by another factor of 100, we can see our own Milky Way galaxy. Of course, no one can journey far enough into space to photograph our galaxy, so this photo shows a similar galaxy with an arrow pointing to a representative location for the sun.

Our sun and the neighboring stars of the previous figure would be lost among the 100 billion stars of the galaxy. Most of the stars are smaller and fainter than our sun, but some are larger and more luminous. Most are cooler, but a few are much hotter. Why some stars are larger, more luminous, or hotter than others is one of the mysteries of the universe that we will explore.

Typical of our galaxy are the graceful spiral arms marked by clusters of bright stars and clouds of gas. We will discover that stars are born in great clouds of gas and dust passing through these spiral arms.

Our galaxy is roughly 100,000 ly in diameter, and until about 70 years ago, astronomers thought it was the entire universe—an island universe of stars in an otherwise empty vastness. Now we know that our galaxy is not unique. Indeed, ours is only one of billions of galaxies scattered throughout the universe.



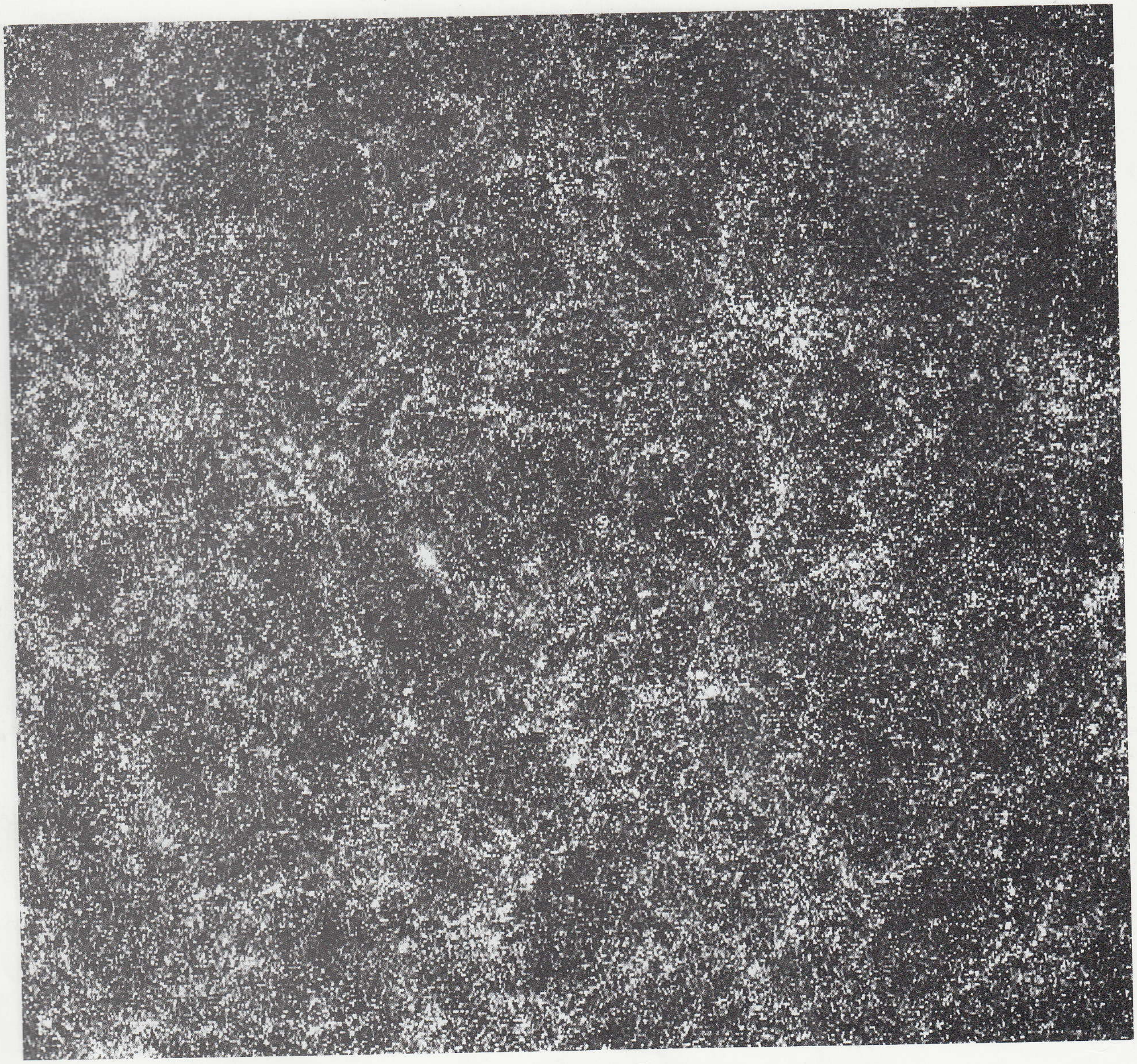
Field of view enlarged 100 times from previous image

As we expand our field of view by another factor of 100, our galaxy becomes a tiny luminous speck surrounded by other specks. This diagram includes a region 17 million ly in diameter. Each of these dots represents a galaxy.

We see that our galaxy (arrow) is one of a small cluster of galaxies. This Local Group consists of roughly two dozen galaxies scattered throughout a region about 6 million ly in diameter.

Among the galaxies we see here, a few are as large as our own galaxy, but most are smaller. A few have the beautiful spiral features we see in our galaxy, but most do not. Among more distant galaxies we see a few galaxies twisted into peculiar shapes or wracked by violent eruptions. Although astronomers understand why stars differ from one another, no one is sure what makes one galaxy different from another. We will find some clues to the mystery when we compare the clusters of galaxies.

One theory holds that the centers of some galaxies contain supermassive black holes, which are capable of swallowing stars whole. Whatever the truth, the evolution of galaxies must occasionally be marked by events of titanic violence.



Field of view enlarged 100 times from previous image. This box ■ represents relative size of previous frame. (Detail from galaxy map from M. Seldner, B. L. Siebers, E. J. Groth, P. J. E. Peebles, *Astronomical Journal* 82 [1977])

Were we to again expand our field of view, we would see that our Local Group of galaxies is part of a large supercluster, a cluster of clusters. Other galaxies are not scattered at random throughout the universe but lie in clusters within larger superclusters.

To represent the universe at this scale, we use a diagram in which each dot represents the location of a single galaxy. At this scale we see superclusters linked to form long filaments outlining voids that seem nearly empty of galaxies. These appear to be the largest structures in the universe. Were we to expand our field of view yet another time, we would probably see a uniform sea of filaments and voids. When we puzzle over the origin of these structures, we are at the frontier of human knowledge.

Our problem in studying astronomy is to keep a proper sense of scale. Remember that each of the billions of

galaxies contains billions of stars. Most of those stars probably have families of planets like our solar system, and on some of those billions of planets liquid water oceans and a protective atmosphere may have spawned life. It is possible that some other planets in the universe are inhabited by intelligent creatures who share our curiosity and our wonder at the scale of the cosmos.

SUMMARY

Our goal in this chapter has been to preview the scale of astronomical objects. To do so, we journeyed outward from a familiar campus scene by expanding our field of view by factors of 100. Only 12 such steps took us to the largest structures in the universe.

The numbers in astronomy are so large it is not convenient to express them in the usual way. Instead, we use the metric system to simplify our calculations and scientific notation to write big numbers easier. The metric system and scientific notation are discussed in Appendix C.

We live on the rotating planet Earth, which orbits a rather average star we call the sun. We defined a unit of distance, the astronomical unit, to be the average distance from Earth to the sun. Of the eight other planets in our solar system, Mercury is closest to the sun, and Neptune is currently the most distant at about 30 AU.

The sun, like most stars, is very far from its neighboring stars, and this leads us to define another unit of distance, the light-year. A light-year is the distance light travels in 1 year. The nearest star to the sun is Proxima Centauri at a distance of 4.2 ly.

As we enlarged our field of view, we discovered that the sun is only one of 100 billion stars in our galaxy and that our galaxy is only one of billions of galaxies in the universe. Galaxies appear to be grouped together in clusters, superclusters, and filaments, the largest structures known.

As we explored, we noted that the universe is evolving. The earth's surface is evolving, and so are stars. Stars form from the gas in space, grow old, and eventually die. We do not yet understand how galaxies form or evolve.

Among the billions of stars in each of the billions of galaxies, many probably have planets, but even the nearest stars to the sun are too distant for us to see any planets they might have. We suppose that some of these planets are like the earth, and we wonder if a few are inhabited by intelligent beings like ourselves.

NEW TERMS

scientific notation
astronomical unit (AU)
light-year (ly)

QUESTIONS

1. Why are astronomical units and light-years more convenient for measuring astronomical distances than miles or kilometers?

2. In what ways is our universe evolving?

3. Why do all stars, except for the sun, look like points of light as seen from earth?

4. Why are we unable to see planets beyond the nine in our solar system?

5. Which is the outermost planet in our solar system? Why does this change?

6. In photographs, some stars look larger than others. What does this tell us about the stars?

7. How long does it take light to cross the diameter of our galaxy? of the Local Group of galaxies?

8. What are the largest known structures in the universe?

9. How many planets inhabited by intelligent life do you think the universe contains? Explain your answer.

PROBLEMS

1. How many inches are there in 100 yards? How many centimeters are there in 100 m?

2. If 1 mile equals 1.609 km and the moon is 2160 miles in diameter, what is its diameter in kilometers?

3. The earth rotates once a day and has a radius of 6378 km. With what speed is the equator moving eastward in km/sec? in miles/hour?

4. If sunlight takes 8 minutes to reach the earth, how long does moonlight take?

5. If the earth were transported to the center of the sun, would the moon's orbit lie inside or outside the surface of the sun?

6. How many suns would it take, laid edge to edge, to reach the nearest star?